Landsat-based monitoring protocols for national parks

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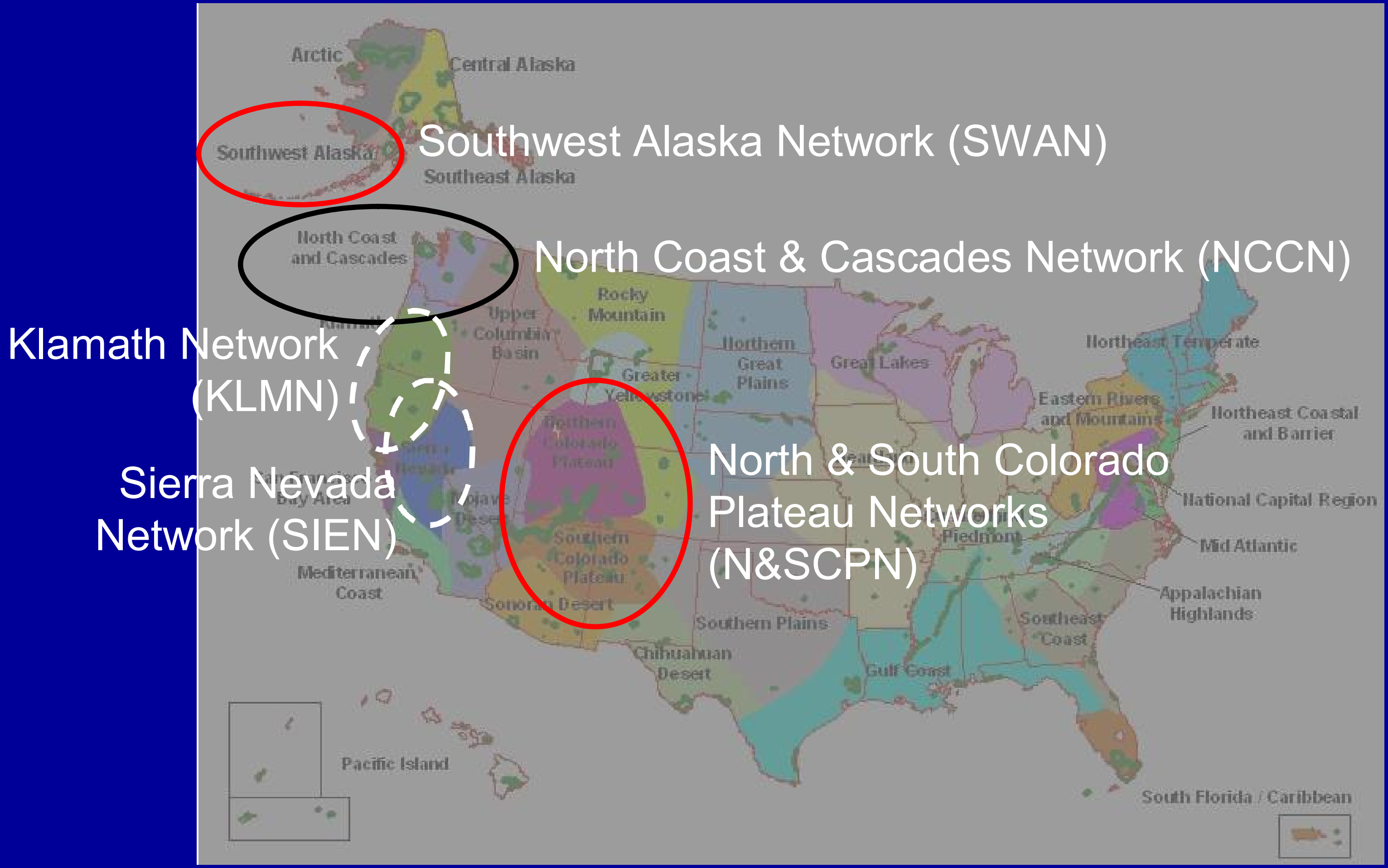
Monitoring in National Parks

- "Natural Resource Challenge" from Congress forces parks to better understand their systems:
  - Inventory & Monitoring Program
- Key goal in many parks: "Landscape dynamics" and/or "Land cover"
  - *Remote sensing*
- National parks grouped into geographic and ecological units
  - Monitoring networks

Our NPS collaborations



Remote sensing for monitoring?

- Monitoring → Change detection
- Challenges:
  - Monitor all cover types
    - *Most change detection studies focus on limited types*
  - Monitor all possible change agents
    - *Most change detection studies focus on a few processes*
  - Reference data limited
    - *Ground & airphoto data often collected WITHOUT RS in mind*
  - Multiple user groups for same change product
    - *Outputs must meet needs of scientists, managers, superintendents, and public*

A key challenge

“-OLOGIST SPEAK”:
Ecologists, Geologists, Botanists, etc.

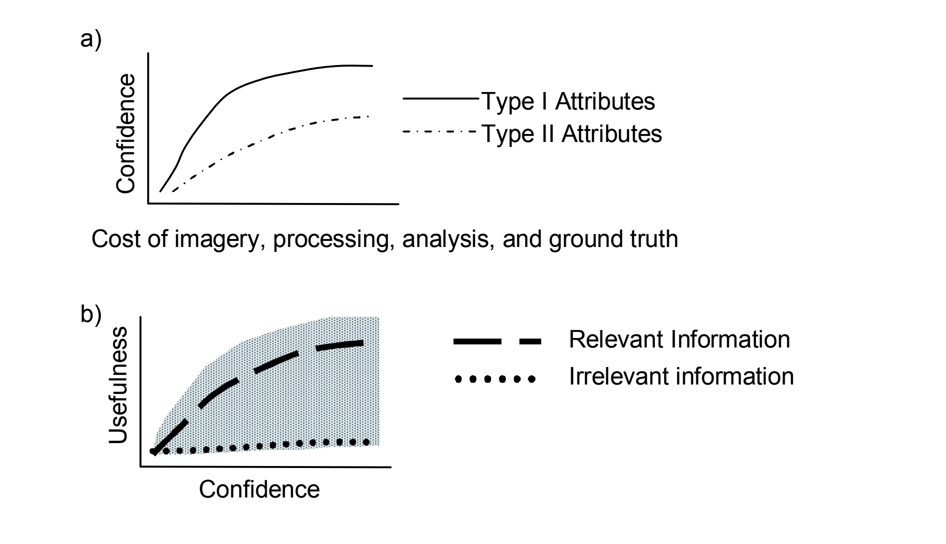
“RS-SPEAK”:
Remote sensing geeks

Reframing goals and solutions

- Cost/Confidence/Utility
- Iterative process
- A question of communication

Detecting a given attribute

But is that attribute useful?



- Questions re-framed → Novel solutions

Focal questions

- What process do you want to monitor?
- What are the manifestations of that process on the landscape?
- At what spatial grain do we need measurements to detect those manifestations?
- How often do we need measurements to capture the process?

Focal questions

- Are the manifestations of desired processes spectrally separable from background?
- Are there sensors that can capture that spectral separation?
- Does the separation rise above levels of background noise over time?

Monitoring goals framed for remote sensing

Table 1. Ecological monitoring goals of the NCCN Parks evaluated January 14th and May 13th, 2004, in Seattle, WA. All goals are characterized in terms of spatial and temporal grain. Based on spatial and temporal grain, as well as importance to the NCCN Parks, each goal was assigned a priority for consideration in the study plan. Those that are also likely to be achievable using Landsat-based satellite data are noted.

Topic	*Sub-topic*	*Spatial Grain*	*Temporal Grain*	*Priority*	*Achievable monitoring goal?*
Alpine Vegetation	Bare ground impacts	1m	5 y	Skip (need higher resolution)	
	Interface w/forest	1m / 30m	Decadal	High/Advise	YES
	Vegetation Comm.	1m	> Annual	High	Advise
Forest Vegetation	Hardwood/Conifer	30m	> Annual	High	YES
	Forest Structure (classes)	1m / 30m	> Annual	High	YES
Disturbance	Vegetation disturbance in avalanche chutes	1m / 30m	5-10 yrs	High	YES
	Landslides	1m / 30m	Annual / > Annual	High	YES
	Fire	30m	Annual / > Annual	High	YES
	Insect/Disease	1m / 30m	Annual / > Annual	High	YES
	Windthrow	1m/ 30m	Annual / > Annual	High	YES
	Pollution	?	?	Low (important in future; impacts are not extensive enough to detect at present)	

ETC….

Monitoring goals grouped temporally

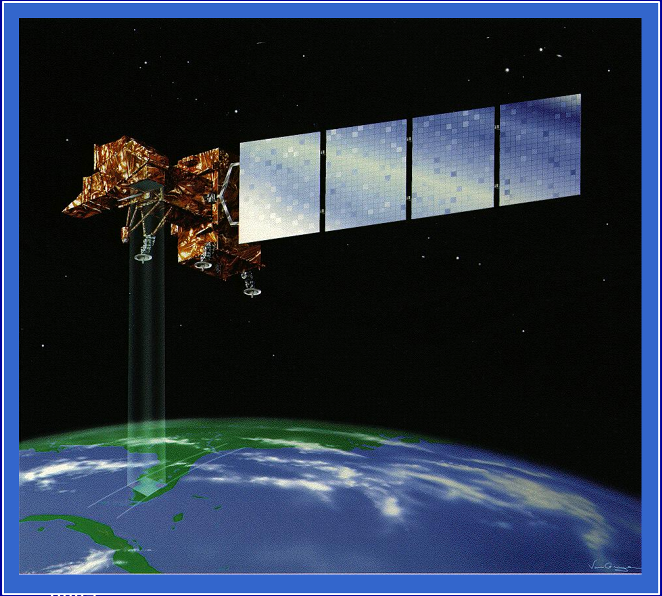
- When and where are these occurring?
  - Use remotely-sensed product as alarm and as measurement tools
- Frequency of monitoring affects
  - Methods of analysis
  - Methods of validation

Table 2. NCCN Monitoring goals grouped by change interval needed for detection

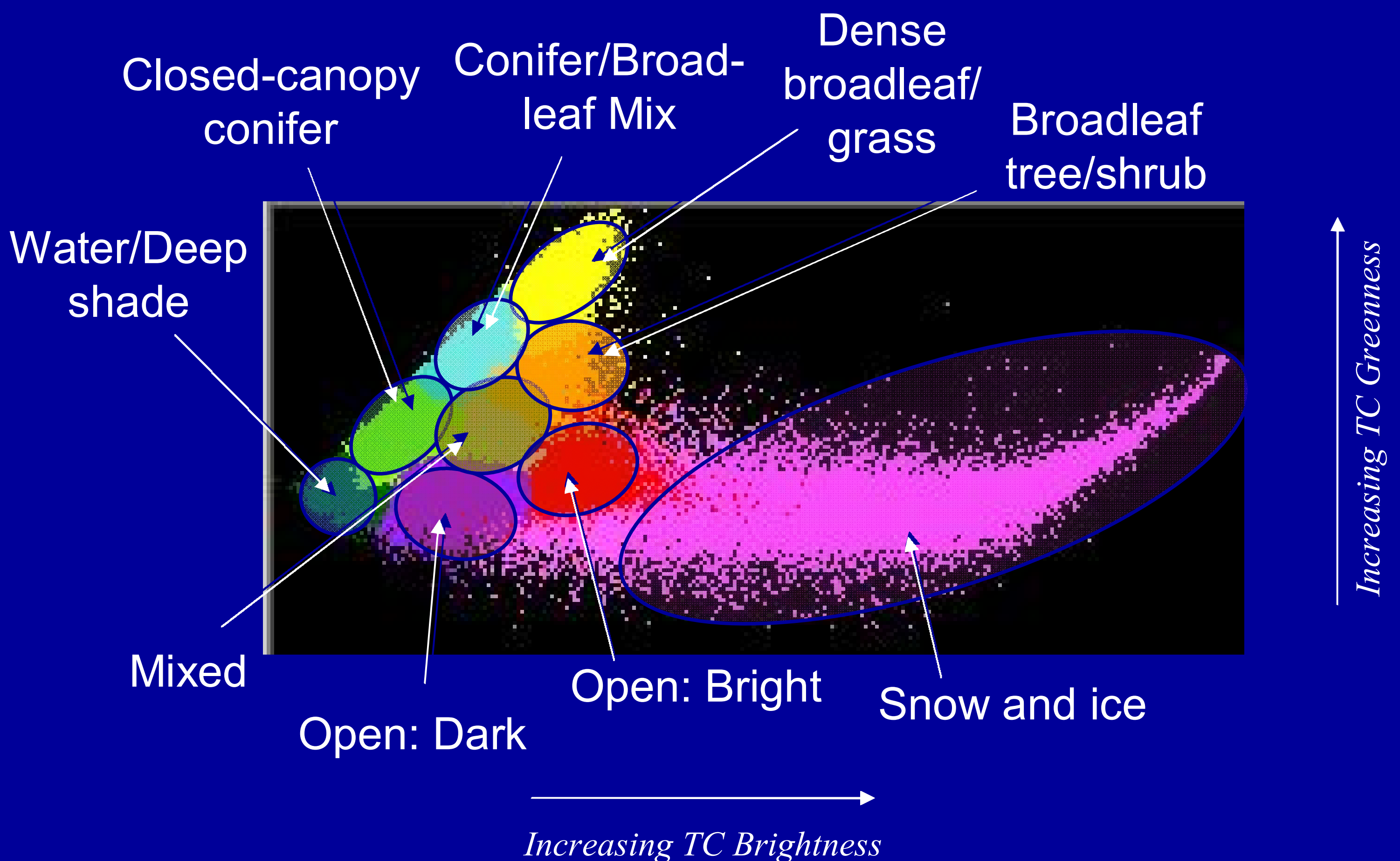
Type 1: Monitor yearly
Avalanche chute clearing
Landslides
Fire
Insect/disease defoliation in forest
Windthrow
Riparian disturbance
Clearcuts
Rural development
Type 2: Monitor decadally
Alpine tree encroachment
Hardwood/conifer forest composition
Forest structure

NCCN: Landsat

- Decision to use Landsat Thematic mapper (TM)
  - Has potential to meet many monitoring goals cheaply and effectively
  - "Eighty percent at half the cost"?
- Characteristics:
  - 1984-present
  - Spatial grain: ~30m
  - Six spectral bands

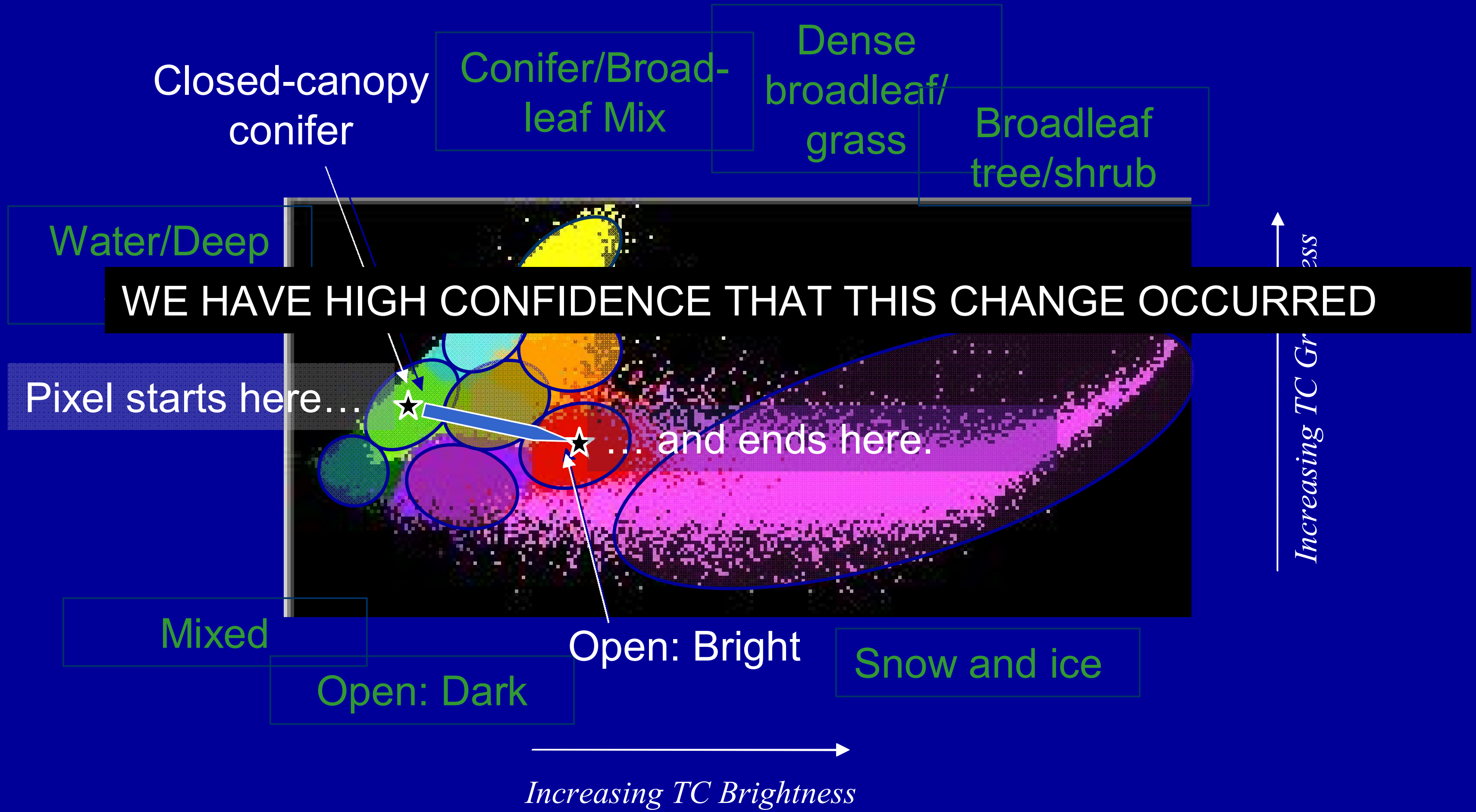


Physiognomic classes



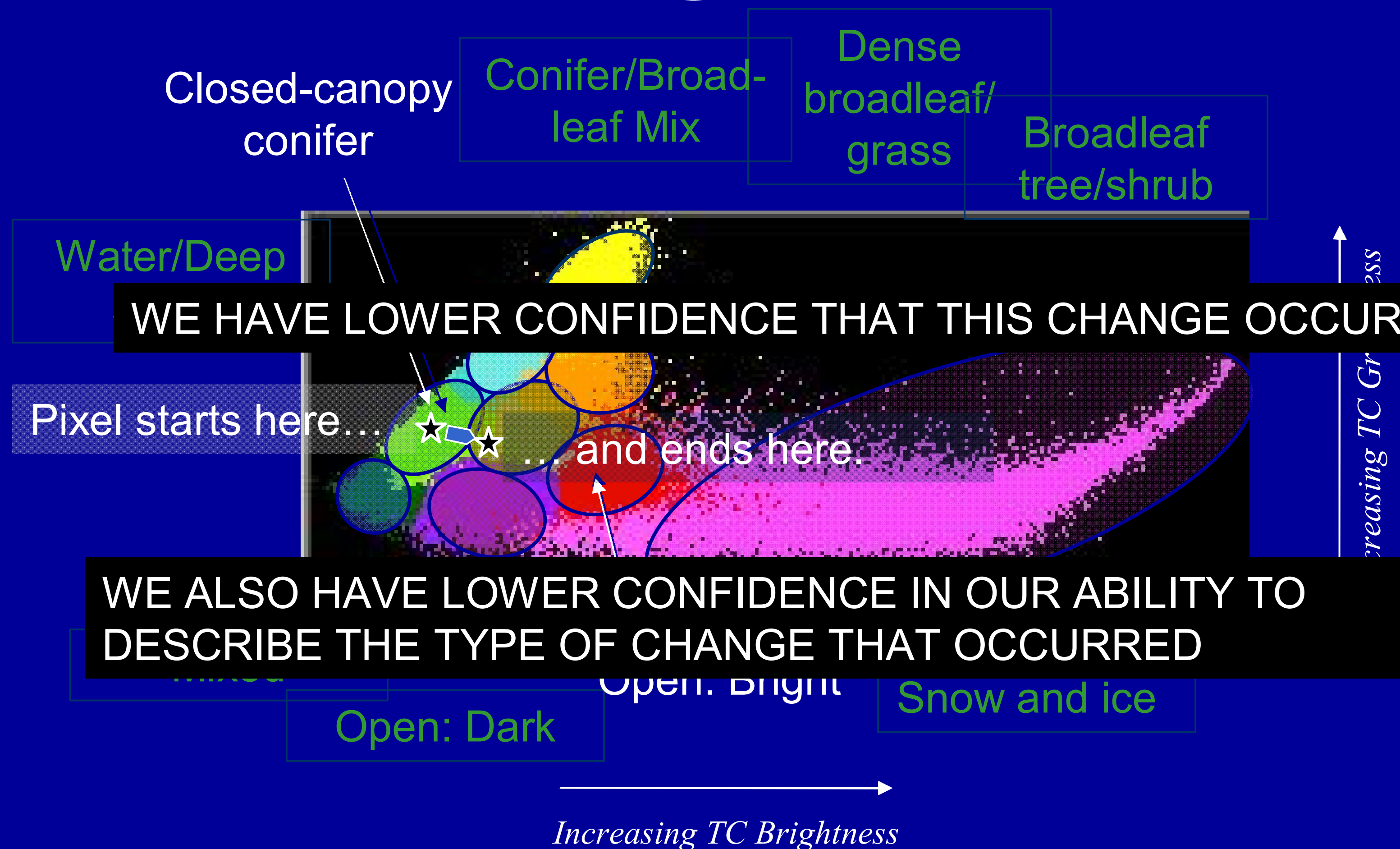
From SOP #3

Change in POM



From SOP #3

Change in POM



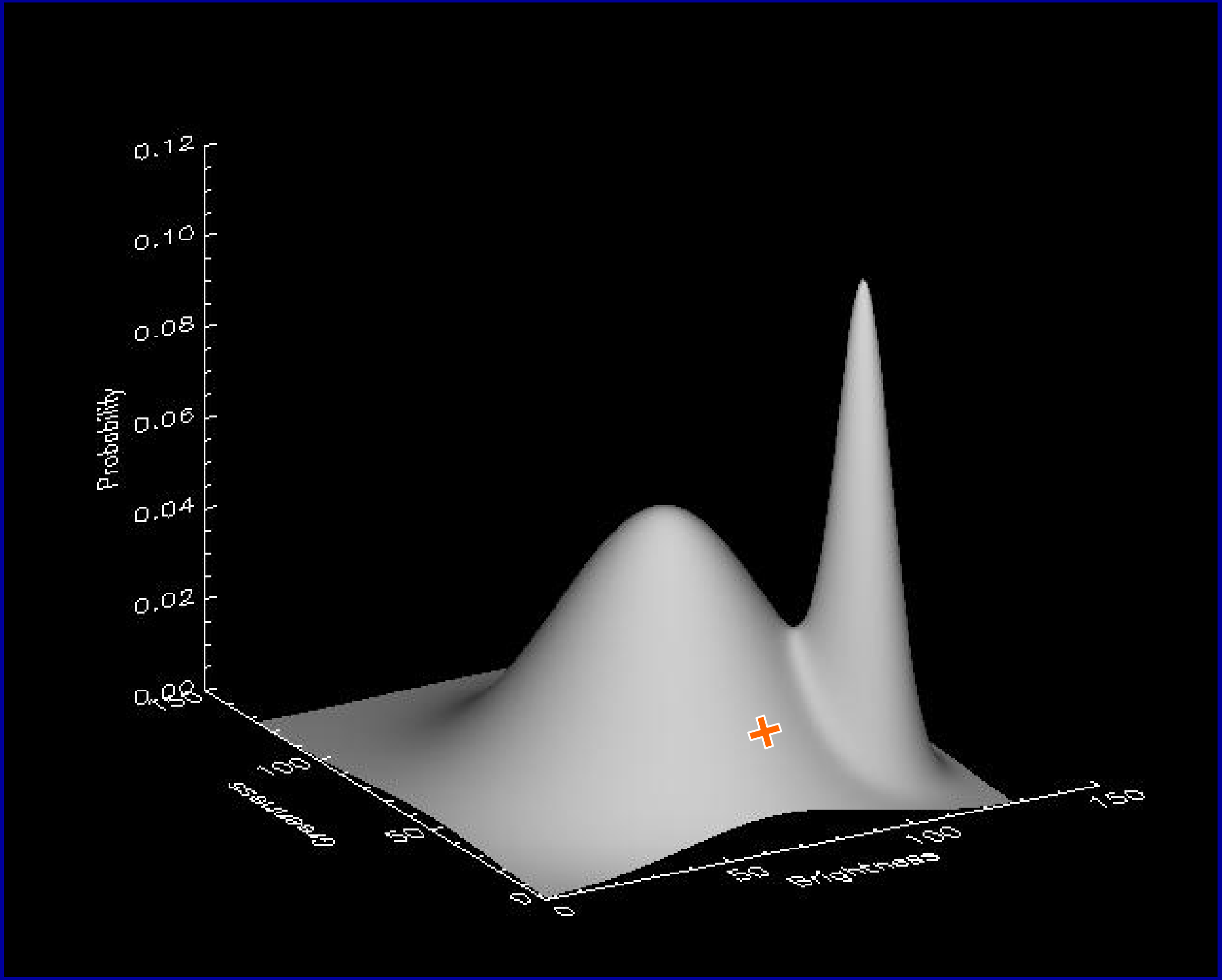
WE HAVE LOWER CONFIDENCE THAT THIS CHANGE OCCURRED

WE ALSO HAVE LOWER CONFIDENCE IN OUR ABILITY TO DESCRIBE THE TYPE OF CHANGE THAT OCCURRED

From SOP #3

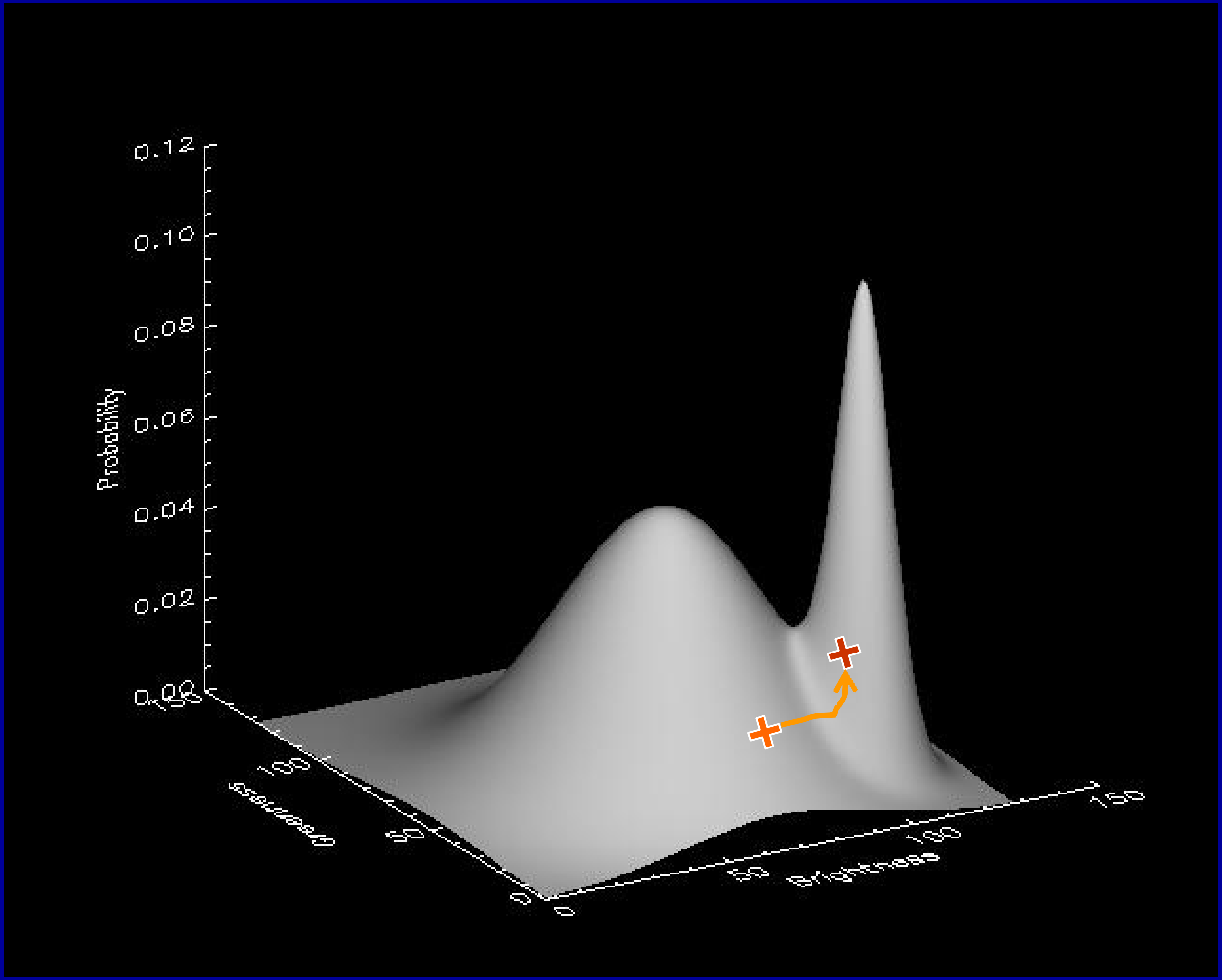
Change in POM

- Consider Classes 1 and 2
- Date 1: likelihood noted with "+"



Change in POM

- Combination of "FROM" and "TO" POM changes helps label change
- Magnitude of combined change tells us about distance in probability space
- Apply this to all physiognomic classes and identify greatest changes



Labeling change

- Subtract probabilities of membership across all classes over time
  - Increases and decreases in probabilities of membership
- Identify largest “from-to” change pair to describe change
- Note absolute value of change – in units of “likelihoods”, akin to probabilities

Difference in POM

- Adjustment of probability threshold allows separation of easy from difficult change goals

Insect mortality near Mt. Rainier

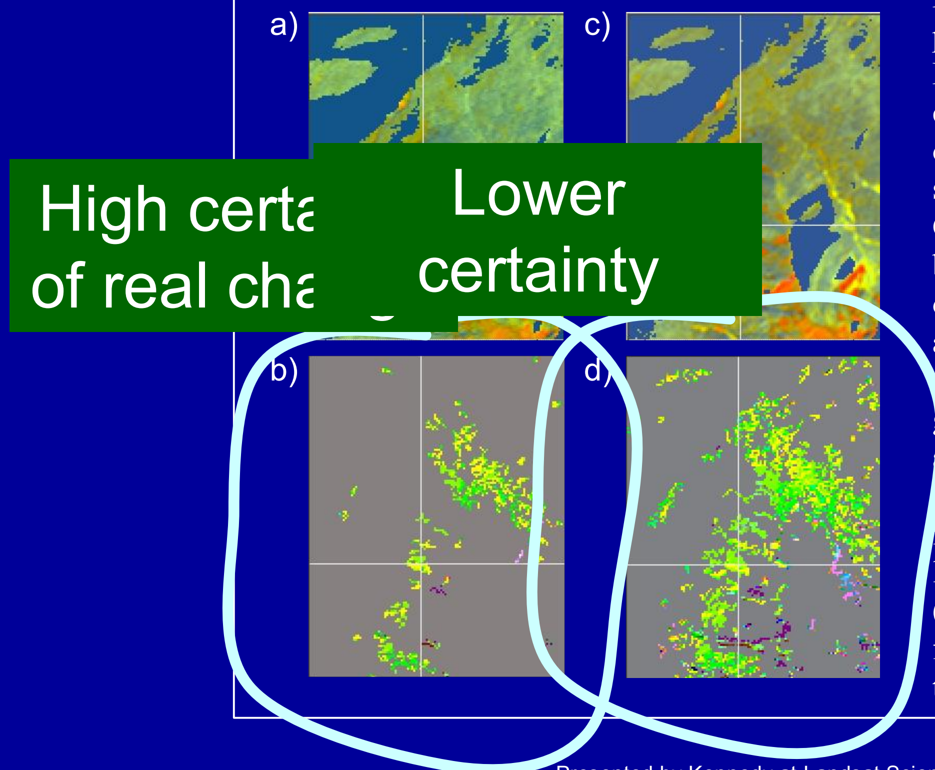
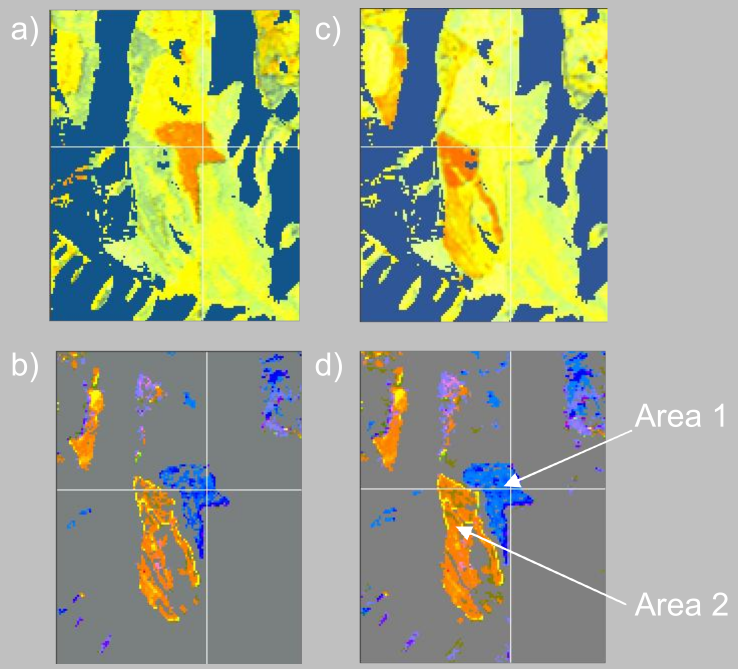


Figure 1. Tasseled cap images and associated change products for an area adjacent to Mount Rainier National Park. a) Tasseled-cap imagery from 1996. Aspect classes are processed separately; this imagery shows only northwest aspects. Tasseled-cap brightness is shown in red, greenness in green, and wetness in blue. Conifer forest appears as light cyan to dark blue, broadleaf vegetation as yellow, and open areas as red or orange. b) The product of the fuzzy change detection approach for the 1996 to 2002 period, showing only areas where probability of membership (POM) in a given class has changed by more than 70%. Red, green, and blue color guns correspond to bare soil, broadleaf, and conifer physiognomic types. Insect mortality results in negative conifer values and/or broadleaf values, leaving yellow (G+R color guns positive) or green (only G color gun positive) tones. c) As in part a, but for the year 2002. d) As in part b, but for a change threshold of 50% rather than 70%.

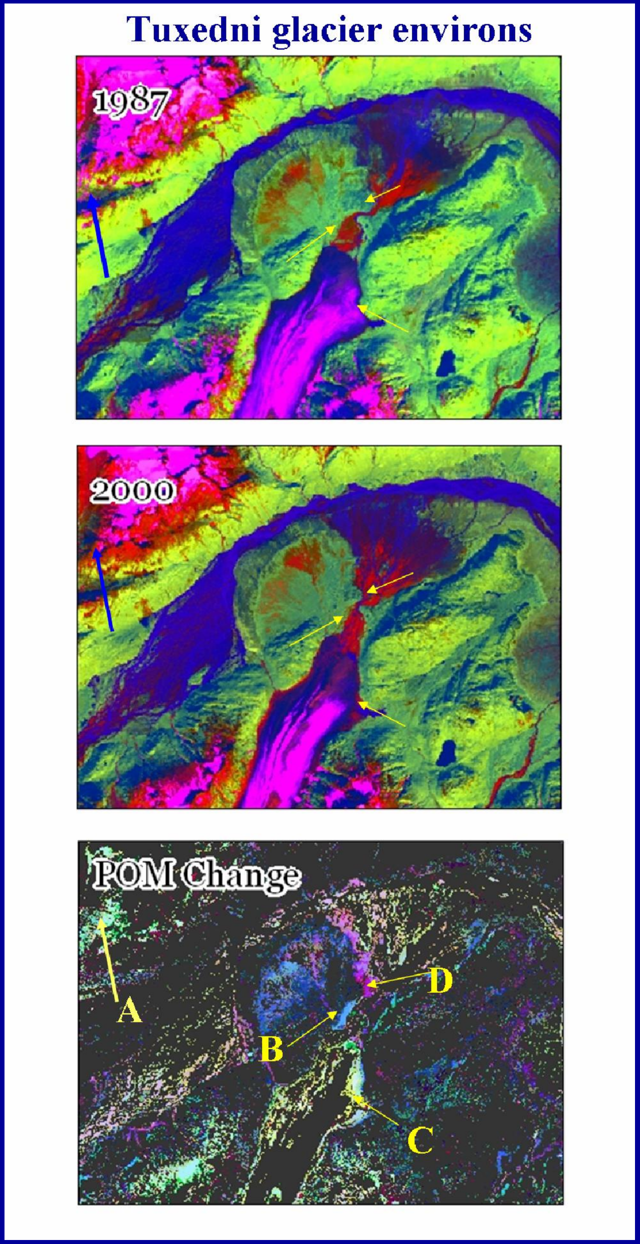
Ecological monitoring



e)

	POM Change Area 1	POM Change Area 2
Water/Deep shade/Old Conifer	0	0
Closed-canopy conifer	0	-1
Conifer-Broadleaf Mix	31	-95
Broadleaf tree/grass	-4	0
Bare soil	0	0
Open mixed/broadleaf	0	-25
Open mixed/conifer	-97	43
Snow and Ice	0	0

Figure 2. (a-d) As in Figure 1, but for a different area near the park, and with RGB color guns in b) and d) corresponding to open mixed/conifer, open mixed/broadleaf, and conifer-broadleaf mix, respectively. e) Scores for pixels in the two areas shown in part d). Changes are differences in probability of membership for each of the eight physiognomic classes listed on the left-hand column of the table. The directional movement in POM allows interpretation of the changes occurring on the surface directly from the change product alone.



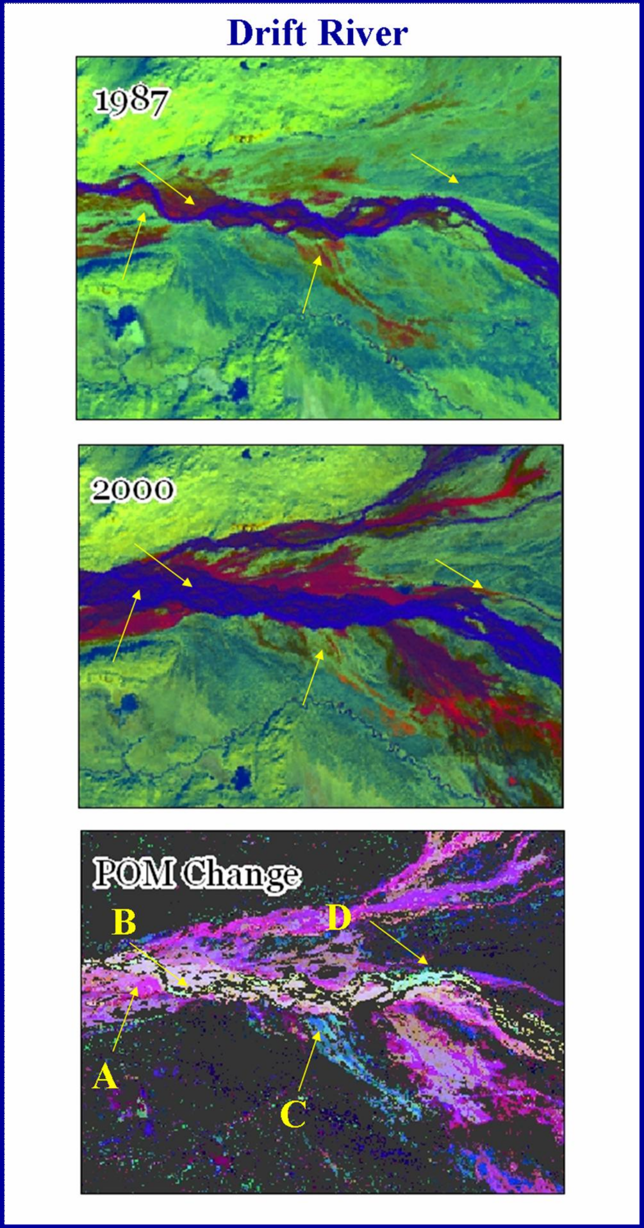
Change labels:

A: Snow → Gravel/Sparsely vegetated

B: Gravel/Sparsely vegetated → Willow shrub

C: Snow → Silty water/Dirty snow

D: Willow shrub → Gravel/Sparsely vegetated



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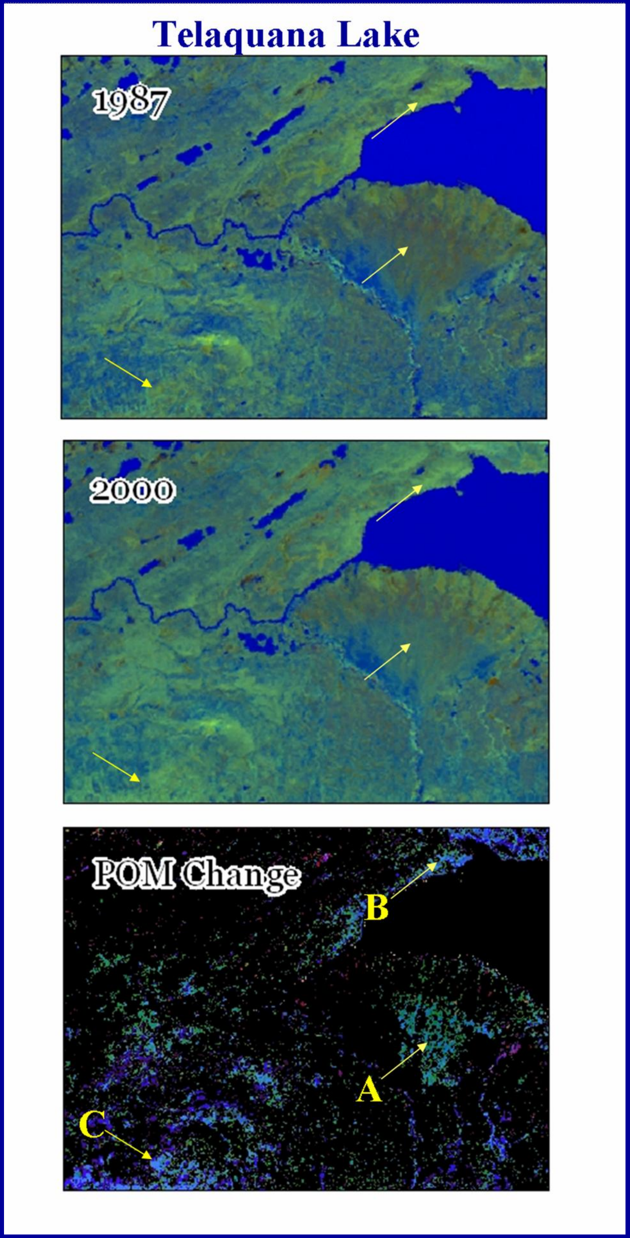
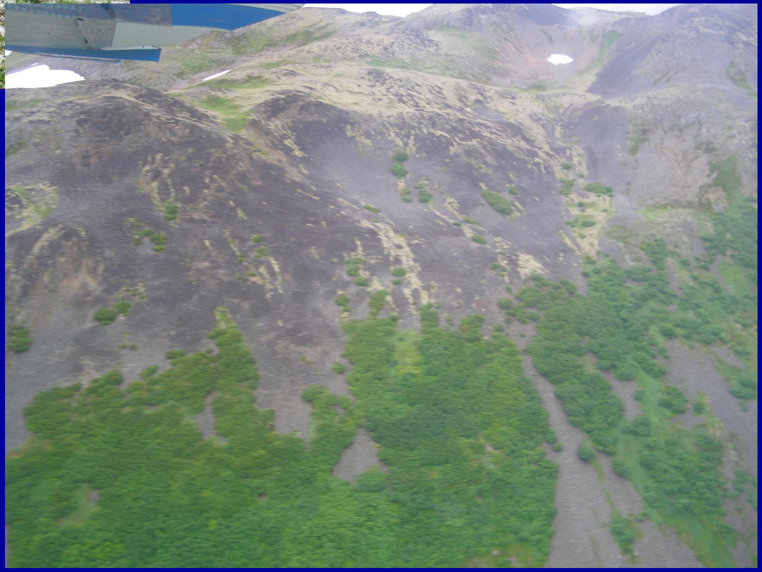


Change labels:

A: Prostrate shrub tundra → Spruce woodland

B: Sedge meadow → Closed alder

C: Sedge meadow → Closed alder



Summary

- Frame monitoring goals in terms of remote sensing
- Process is important
- Validation considered from the beginning
- Consider solutions that are
  - Workable
  - 80% of the goal at half the cost


The end

Extras

Reference data

- Ideal reference data:
  - Independent measurement tool
  - At appropriate spatial grain
  - Distributed across entire landscape
  - Acquired at the same time as imagery
  - Repeated as often as repeat imagery for change detection
- Such data do not exist

Overview of protocol

- Specify detail on ordering and pre-processing of imagery
- Identify physiognomic classes for a baseline image year
- Derive gaussian probability surfaces for physiognomic classes
  - Probability of membership (POM)
- Physiognomic classes overlap in spectral space

Focus on change

- Develop change maps without reference to baseline map
  - Contrasts with N&SCPN and SWAN
    - Baseline mapping w/airphotos
    - Vegetation mapping program of NPS
      - http://biology.usgs.gov/npsveg/
- Frame questions in terms of broad "physiognomic classes"
  - Based on general knowledge of spectral data space

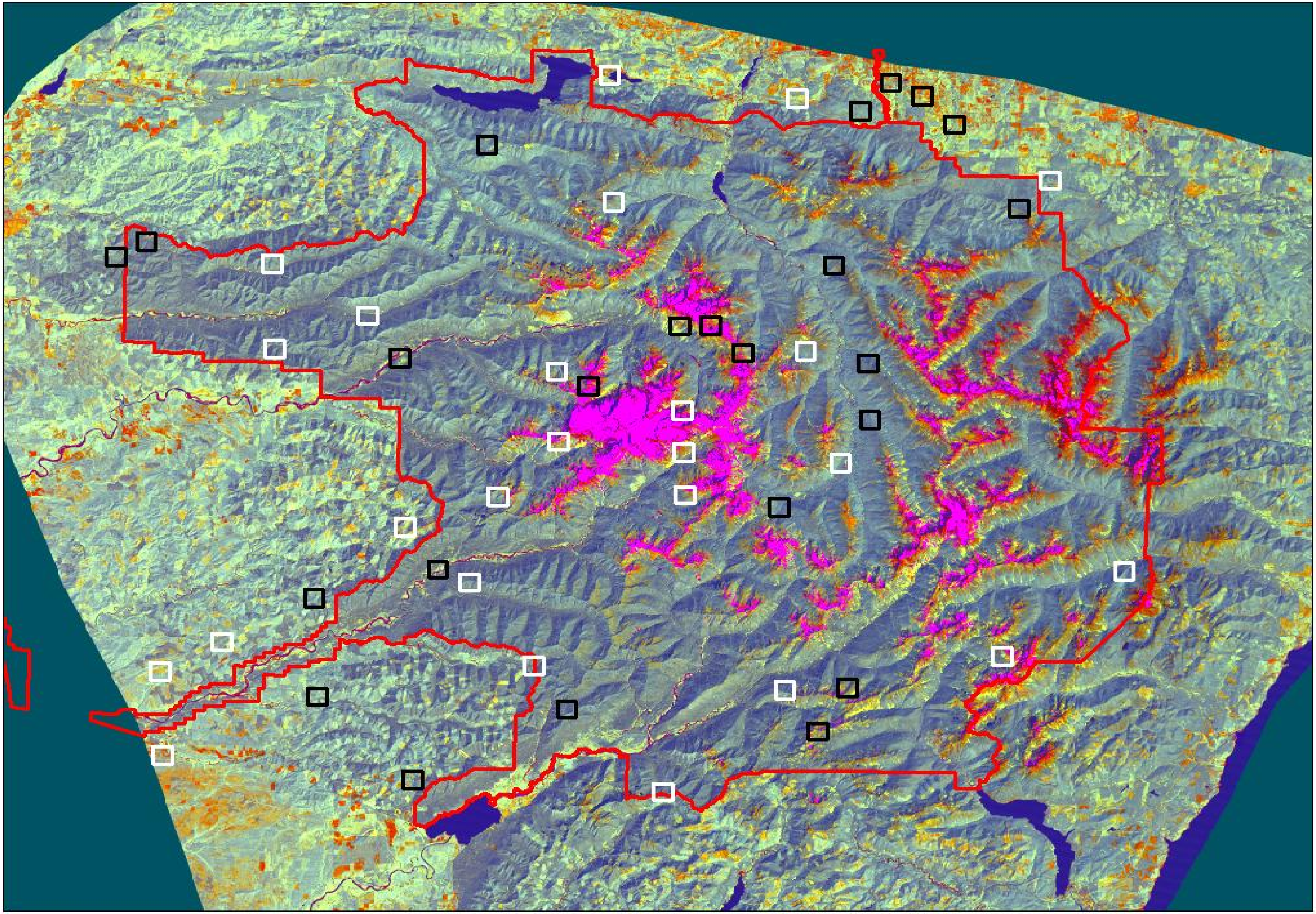
Validation

- Type 1 monitoring (disturbances)
  - Primary approach: direct interpretation of satellite imagery (S2S)
    - On-screen digitization
    - Use rules similar to airphoto interpretation – i.e. shape, size, color, texture of events
    - Assign change type, change agent, and confidence in change
  - Test: Essentially how well the difference in POM approach models the human interpreter

Validation

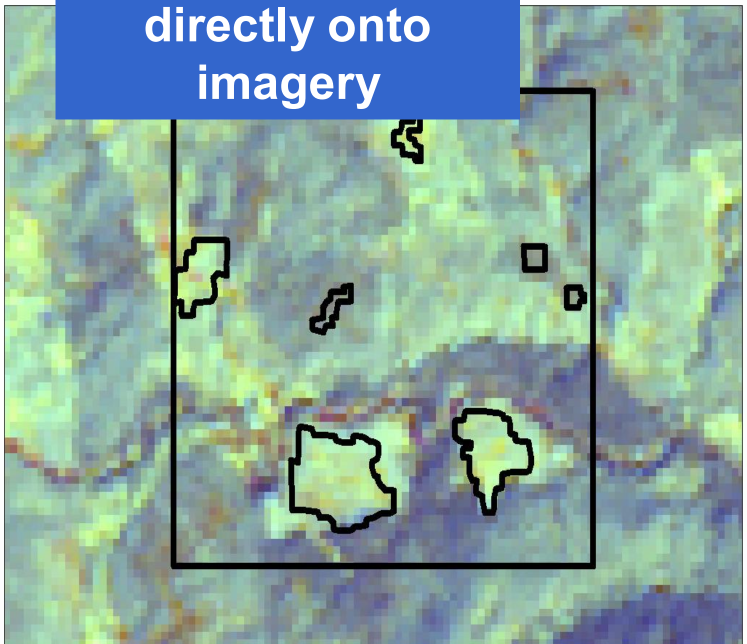
- Type 2 monitoring (encroachment, revegetation)
  - Airphoto-based interpretation
  - Decadal time-step
  - Use this validation to understand accuracy of S2S validation

Testing in white, training in black



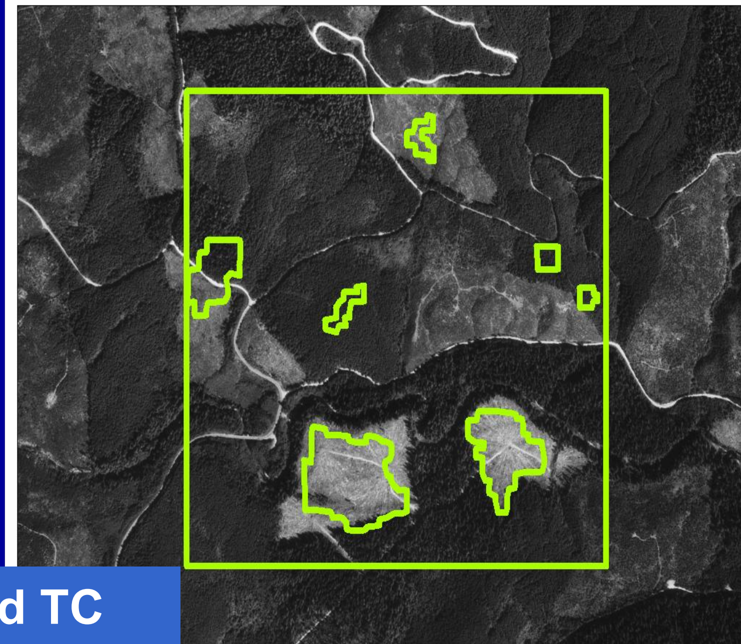
Regrowth at OLYM

Polygons digitized directly onto imagery

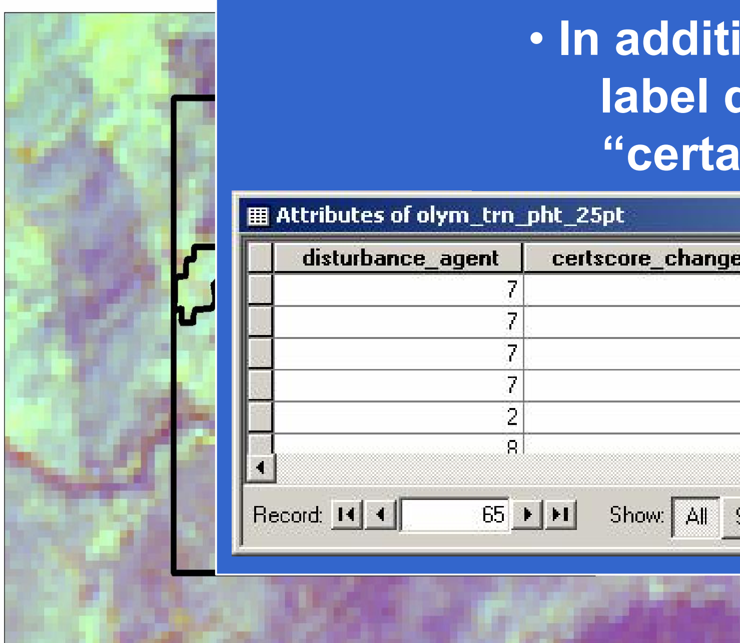


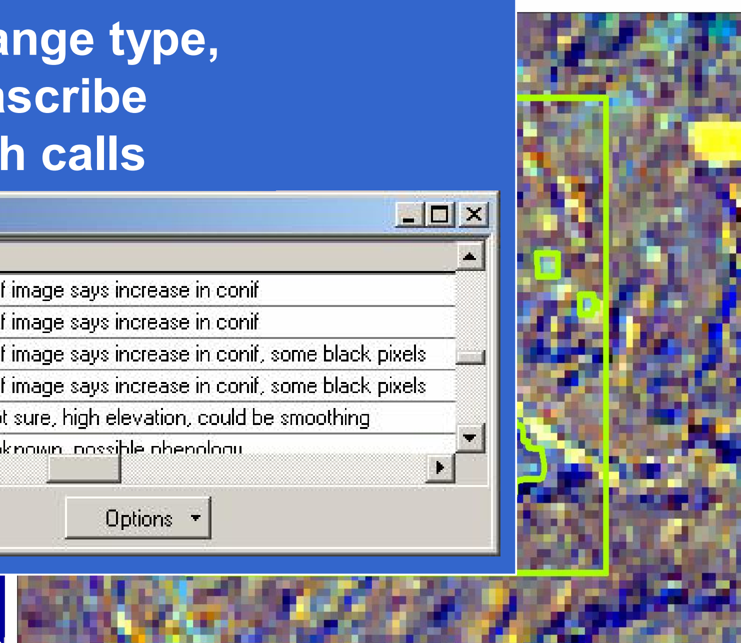
2002 TC

DOQ



DOQs and TC





- **In addition to labeling change type, label disturbance, and ascribe “certainty score” to both calls**

Attributes of olym_trn_pht_25pt

disturbance_agent	certscore_change_type	certscore_dist_agent	
7	4	2	diff image says increase in conif
7	4	2	diff image says increase in conif
7	4	2	diff image says increase in conif, some black pixels
7	4	2	diff image says increase in conif, some black pixels
2	3	2	not sure, high elevation, could be smoothing
8	3	0	unknown, possible phenology

Record: 65 Show: All Selected Records (0 out of 93 Selected.) Options

S2S Disturbance Agent Types

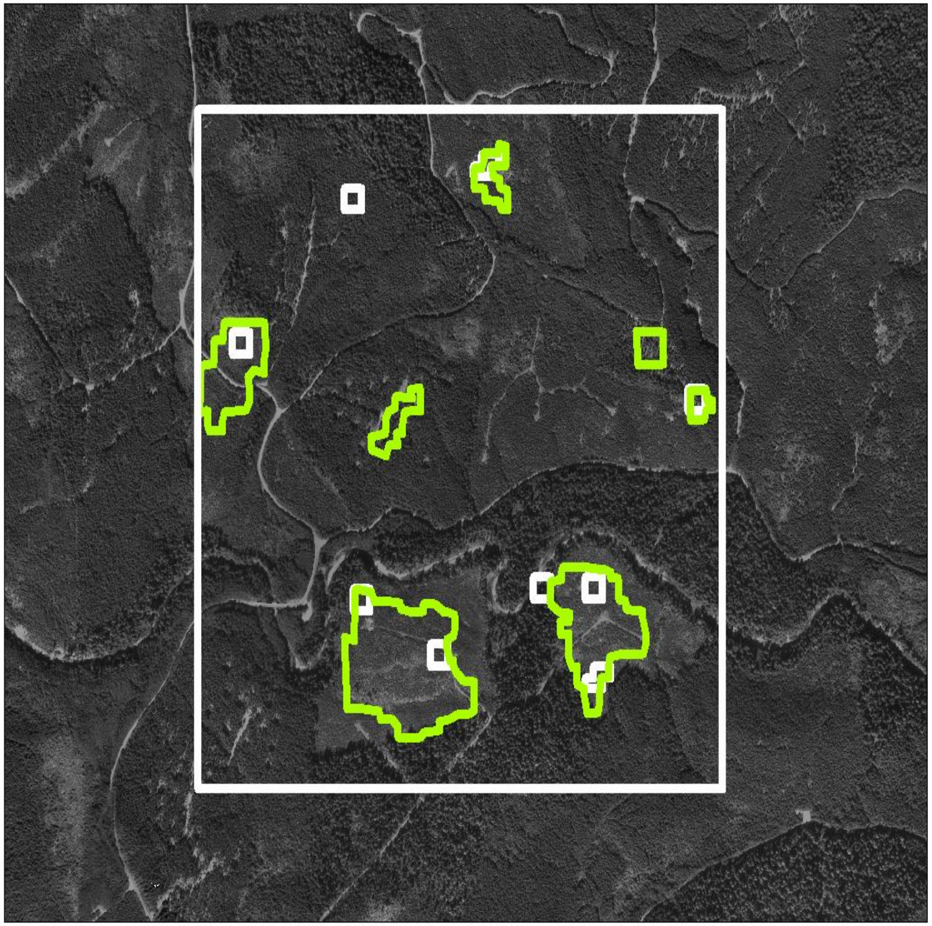
S2S change number	S2S change type
1	no change
2	water to rock/soil
3	water to partial veg cover
4	water to complete veg cover
5	rock/soil to water
6	partial veg to water
7	complete veg to water
8	increase in broadleaf
9	increase in conifer
10	increase in broadleaf and conifer
11	decrease in broadleaf
12	decrease in conifer
13	decrease in conifer and broadleaf
14	increase in snow
15	decrease in snow

Satellite validation

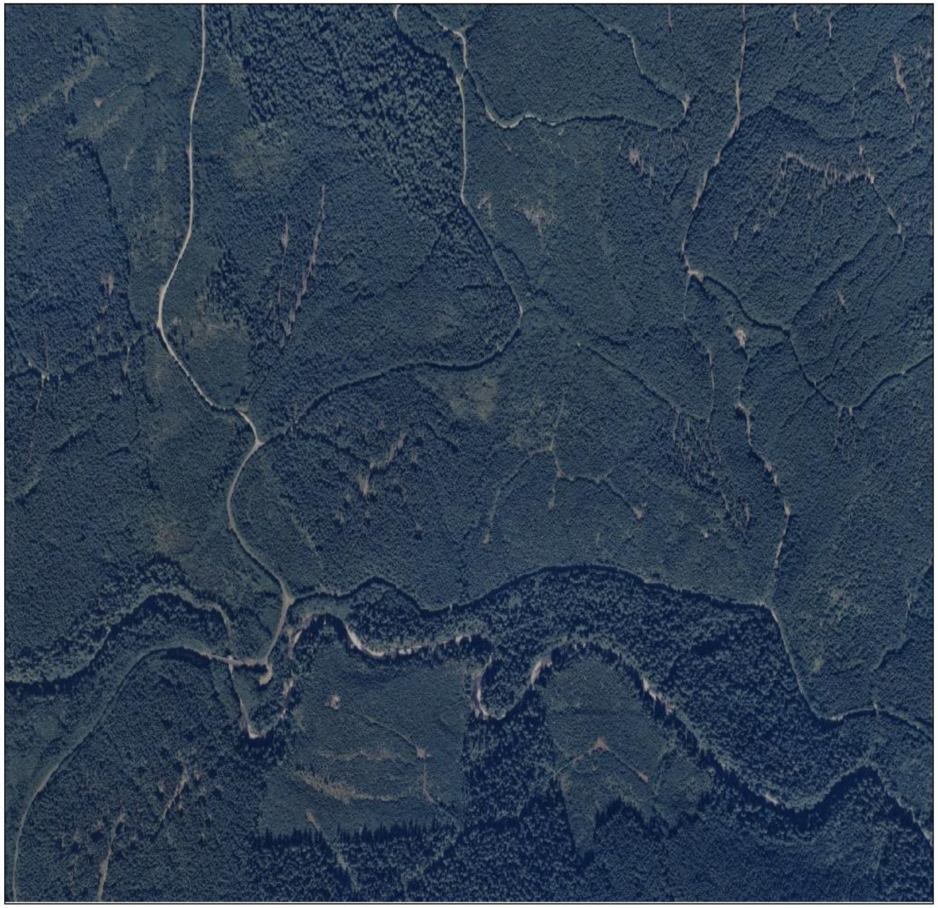
- Testing S2S (satellite-satellite) validation
  - Sample S2S polygons with .25 ha plots
  - Use 2000 DOQs and 2002 scanned airphotos to make change calls
    - Double-blind

Regrowth at OLYM

DOQ



Scanned airphoto



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2	3	2	not sure, high elevation, could be smoothing
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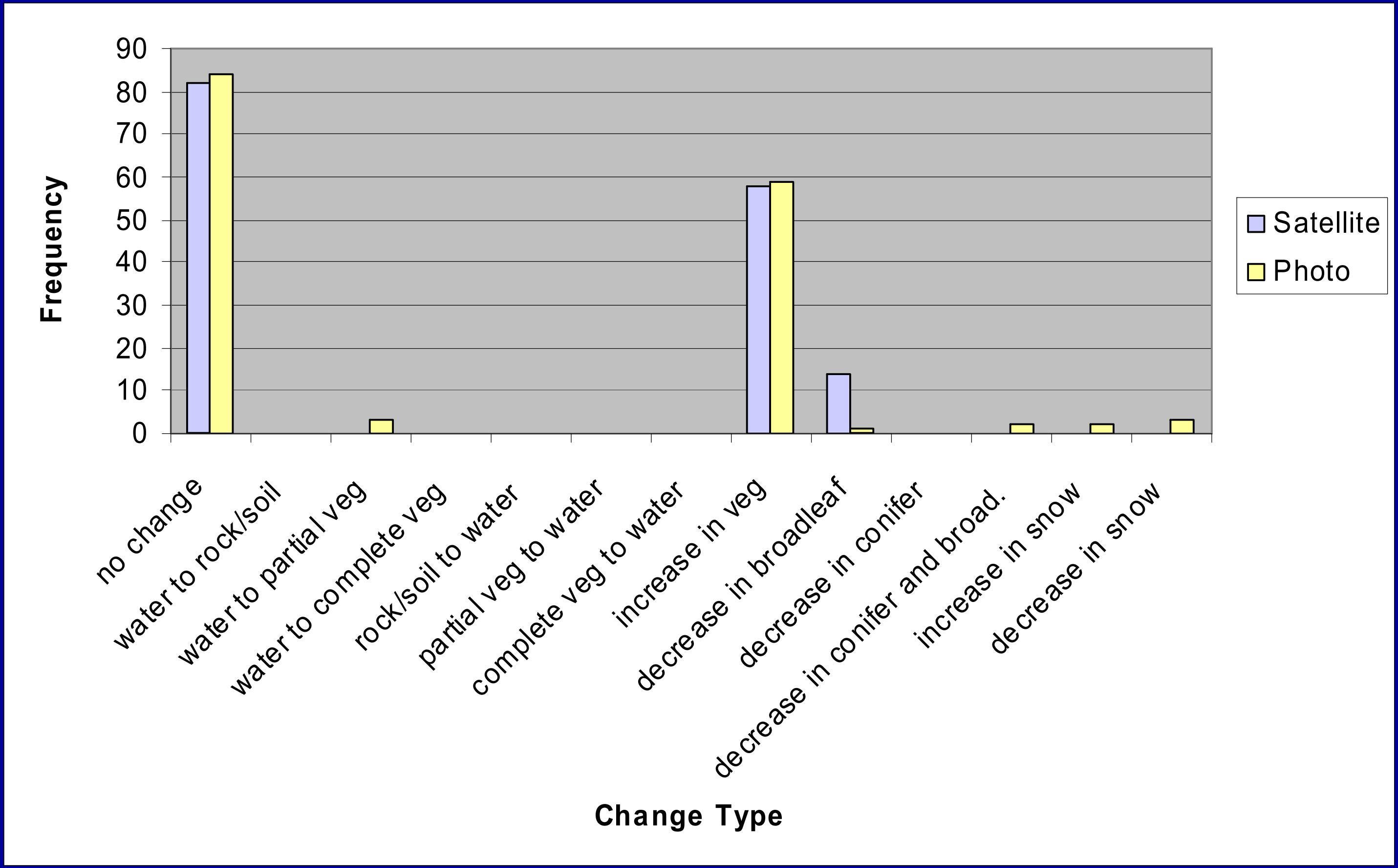
Record: 65 Show: All Selected Records (0 out of 93 Selected.) Options

S2S and Air Photo Comparison with vegetation increase change types collapsed into one category



Validation

- Third level of validation: field
  - Cost prohibitive
  - Protocol defines options for opportunistic, on-the-ground “yea/nay” validation
    - Piggy-back on to other field efforts
  - Sampling design a key concern

Accuracy Assessment: Error matrix

- Summarize using an error matrix

	Class types determined from reference source				
Class types determined from classified map	# Plots	Conifer	Hardwood	Water	**Totals**
	Conifer	50	10	2	62
	Hardwood	7	20	0	27
	Water	3	0	8	11
	Totals	60	30	10	100

Accuracy Assessment: *Kappa*

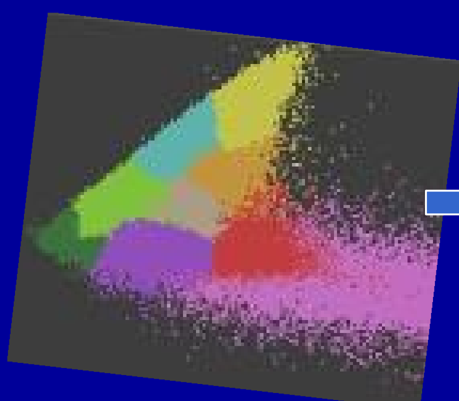
- *Kappa* statistic
- Estimated as $\hat{K}$
- Reflects the difference between actual agreement and the agreement expected by chance

$$\hat{K} = \frac{\text{observed accuracy - chance agreement}}{\text{1 - chance agreement}}$$

Radiometric correction

Spectral space of radiometric reference image

Spectral space of newly-purchased image



Basic atmospheric correction; relative normal-ization

Spectral space of “fixed” image

Overview of methodology

EXAMPLE: NOCA

PMR Field Data

1994
Image: July 31

Radiometric reference image

Airphotos 1:12,000

1998
Image: Aug 27

Geometric reference image

Geocover Image: Aug 11

2001

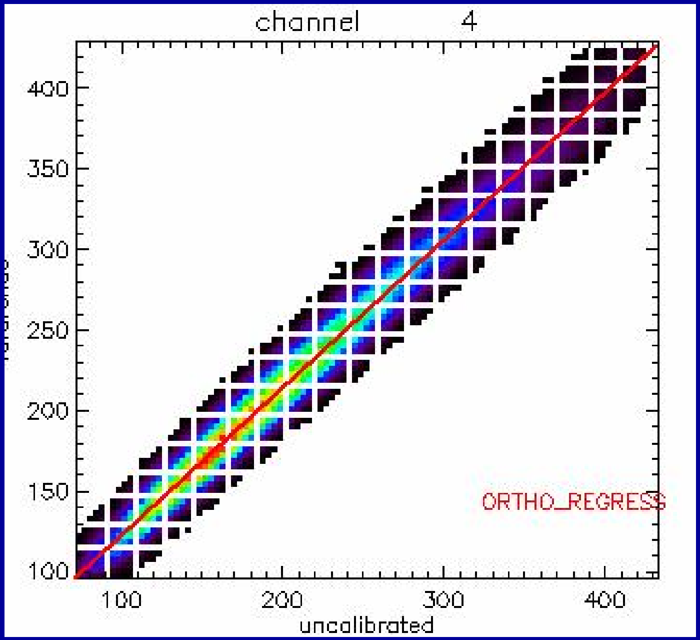
2004
Image: July 26

Initial Change Detection

Ongoing Change Detection

Relative normalization

- MADCAL
  - Use "multivariate alteration detection" to identify pixels that are stable across all bands for a reference image and a subject image
  - Develop regressions on a *band by band* basis to map subject image numbers into reference image



Certainty scoring

Change type: 0-5

Spectral change vector is distinct from change vector of similar starting types in surrounding area 0, 1, or 2

Area of spectral change is large and consistent within "patch": 0 or 1
Change is clearly not caused by misregistration: 0 or 1

Spectral condition of endpoints is interpretable and consistent with change call: 0 or 1

Disturbance agent: 0-3

Shape is consistent with disturbance agent: 0 or 1

Size is consistent with disturbance agent: 0 or 1

Landscape position and context is consistent with disturbance agent: 0 or 1

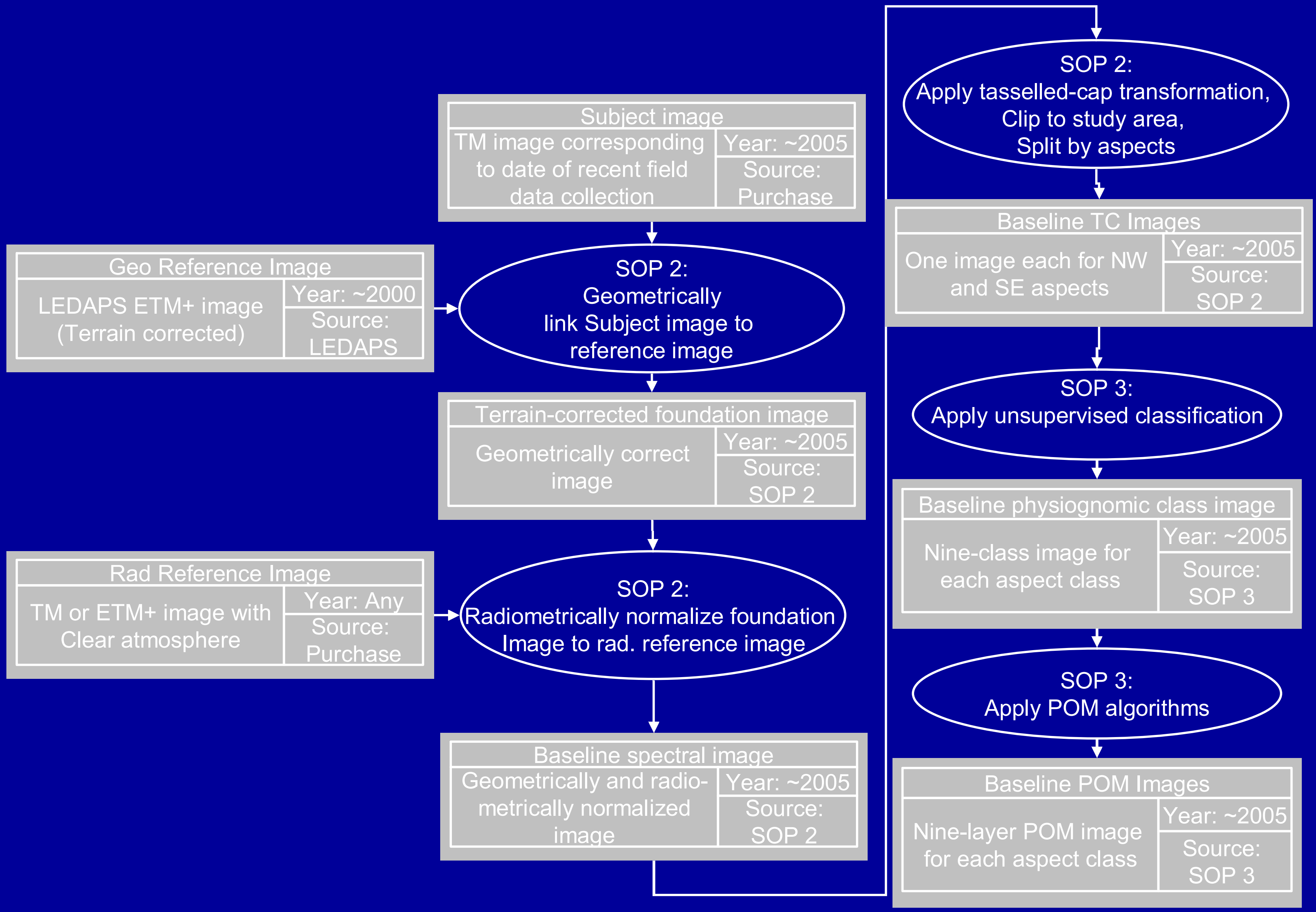


Figure 5. Startup phase.

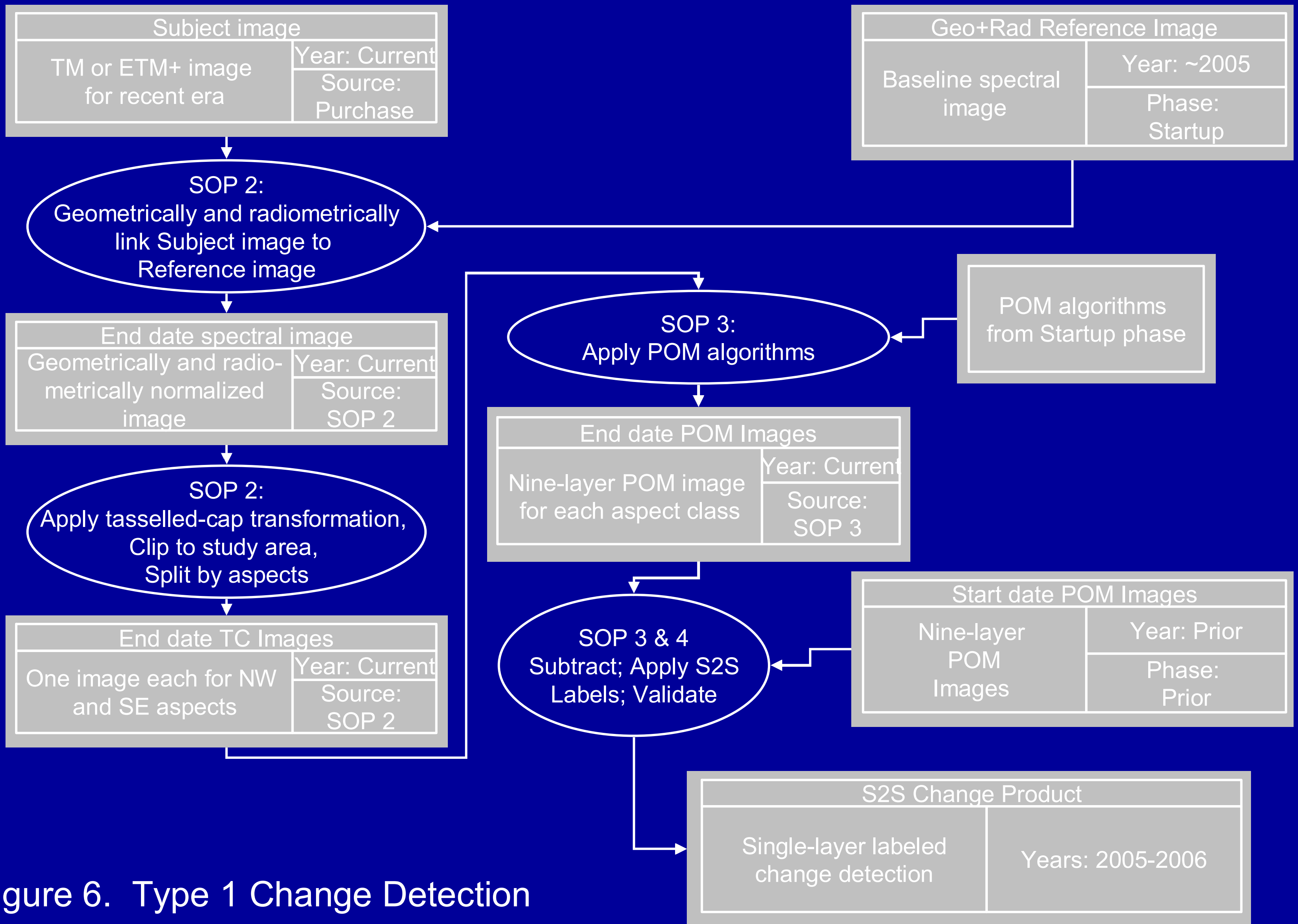


Figure 6. Type 1 Change Detection

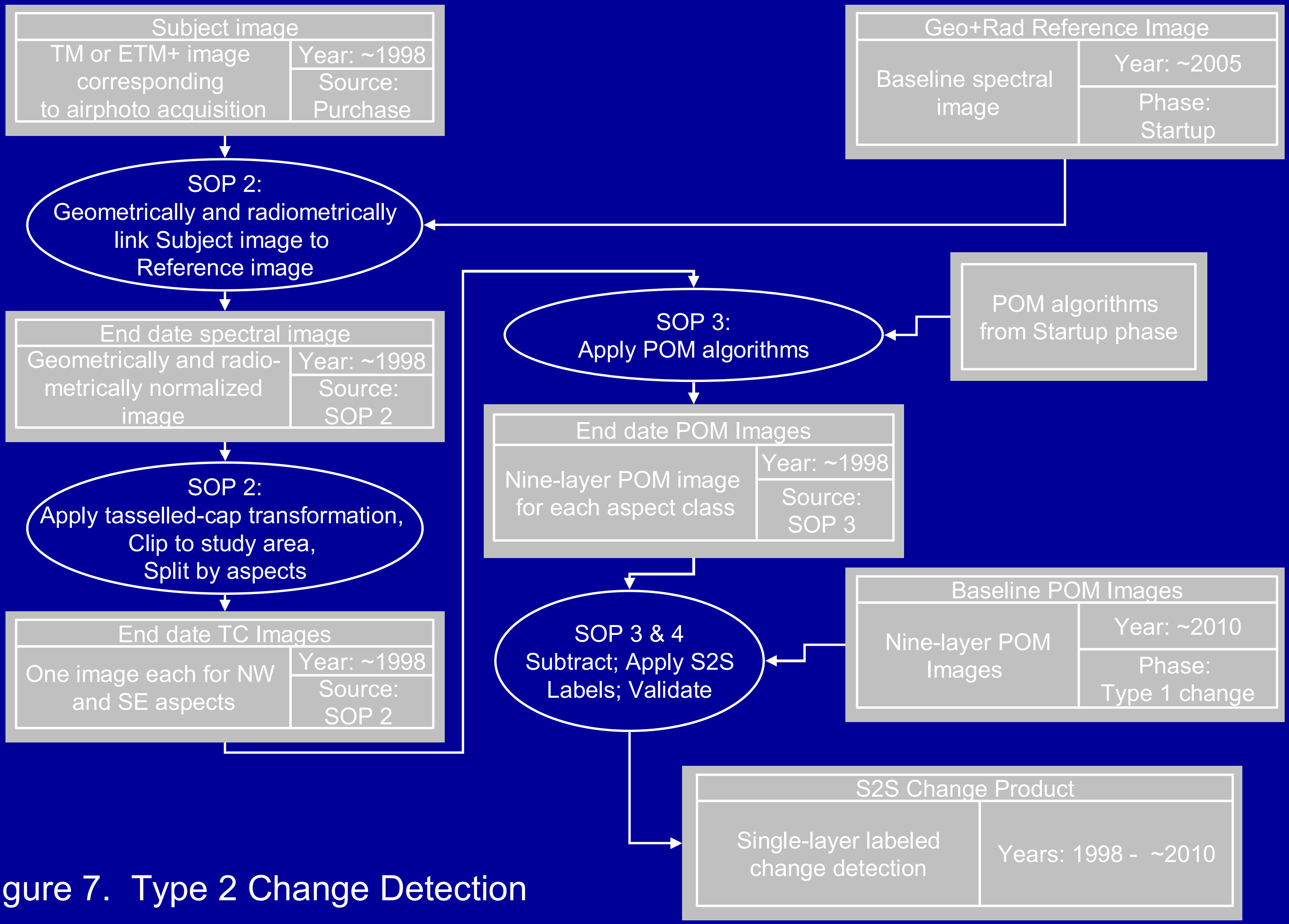
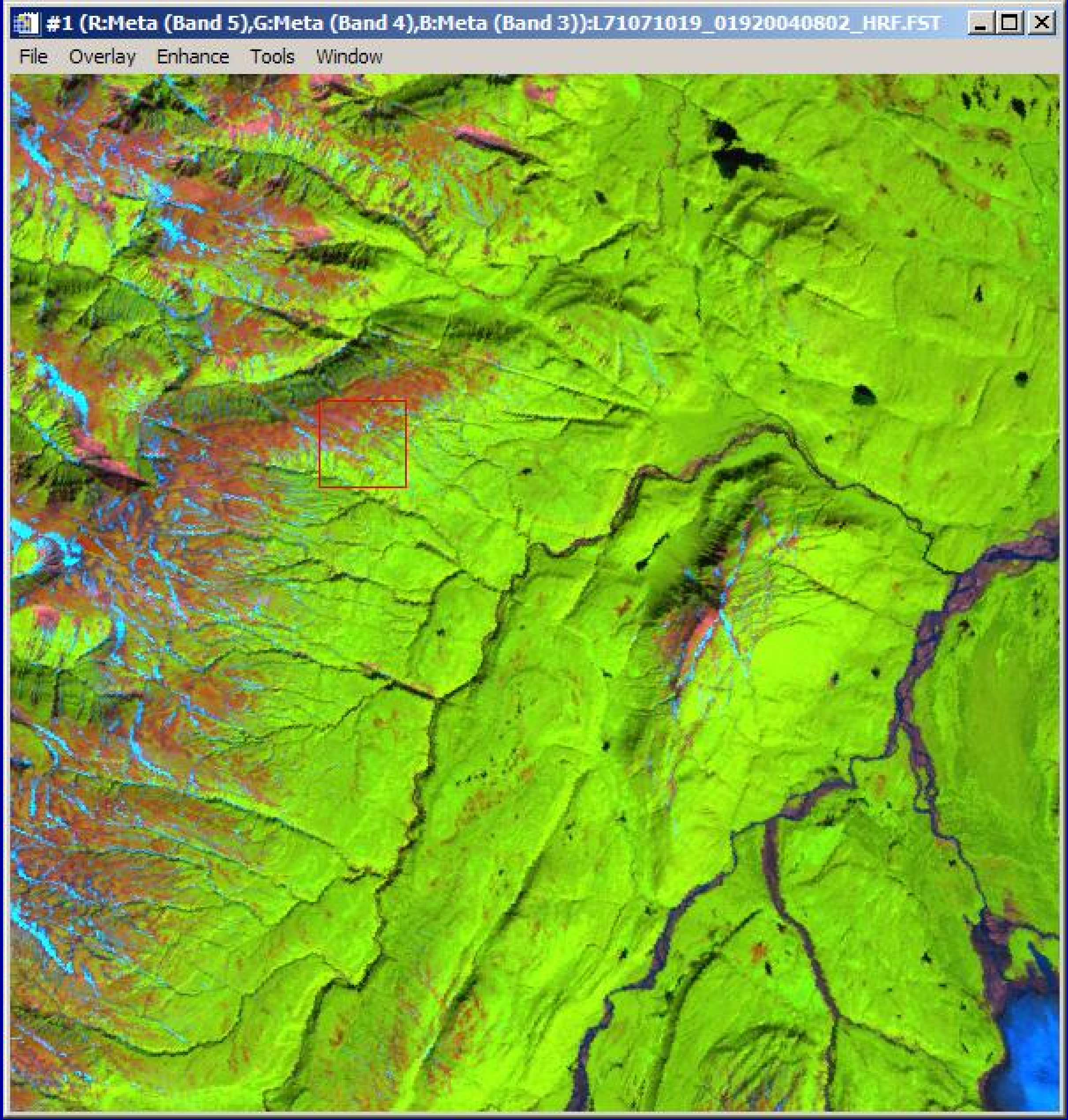
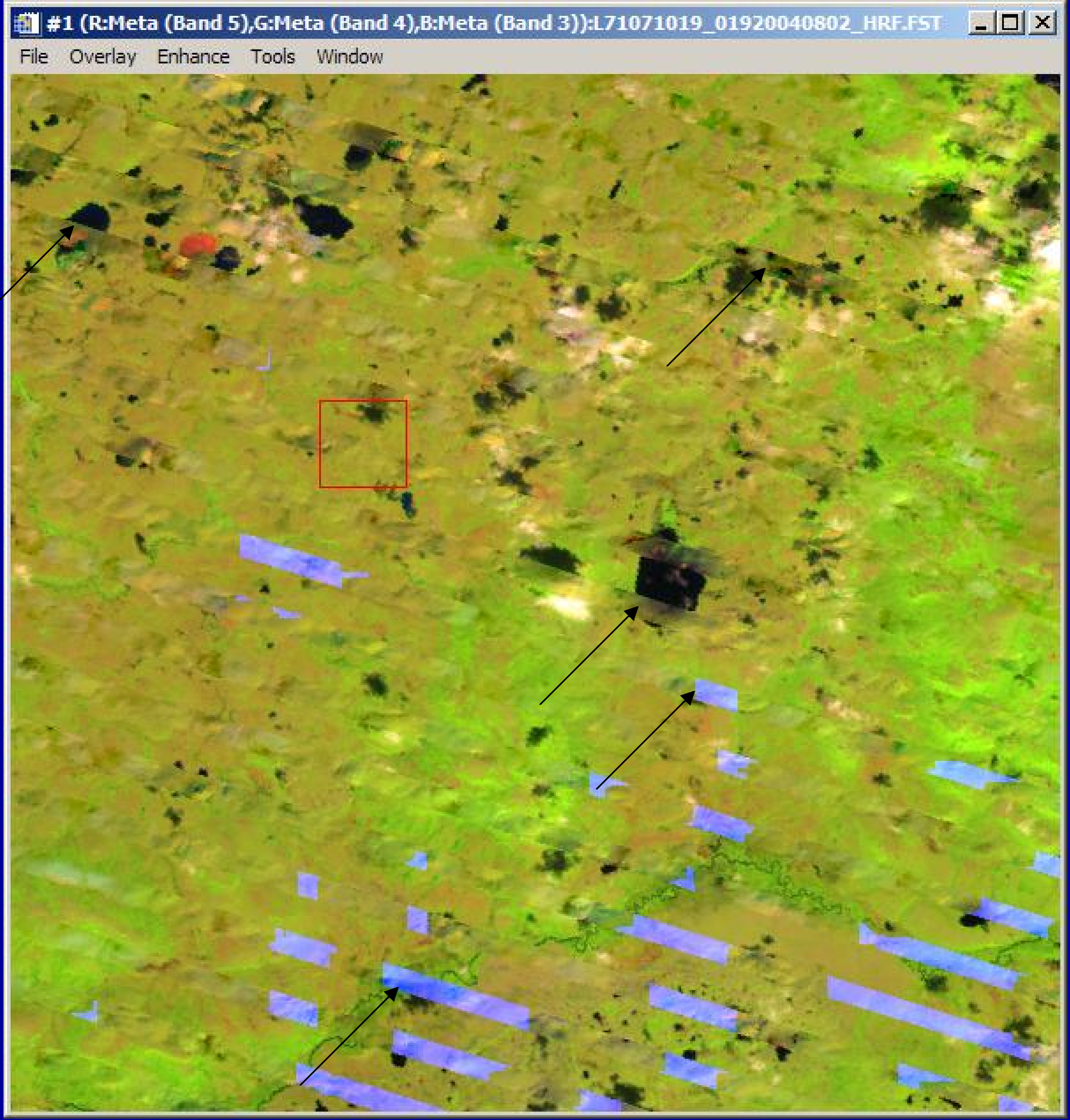


Figure 7. Type 2 Change Detection

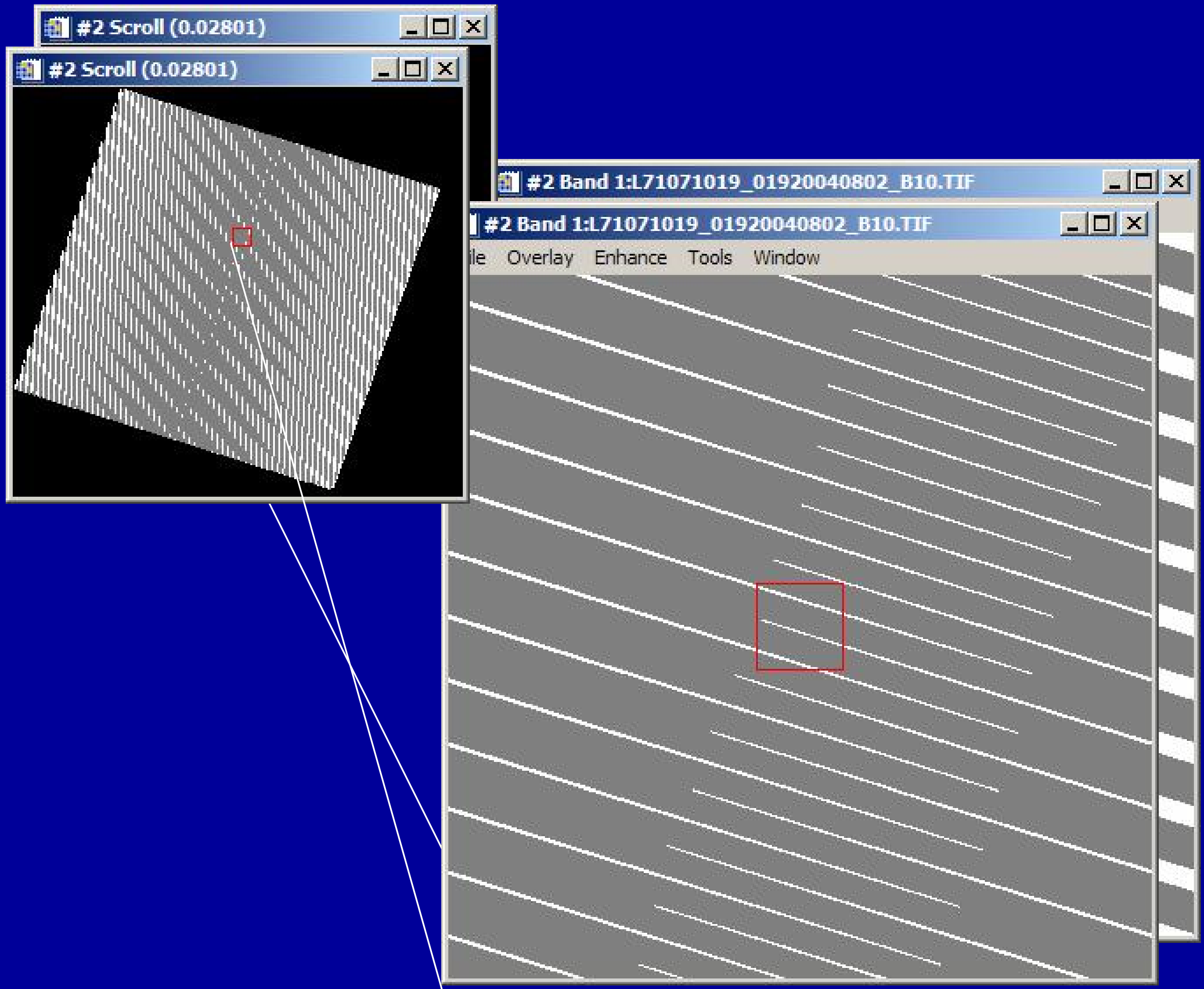
Ex 1: No noticeable problems with gap-filling



Ex 2: Quite noticeable problems with gap-filling!



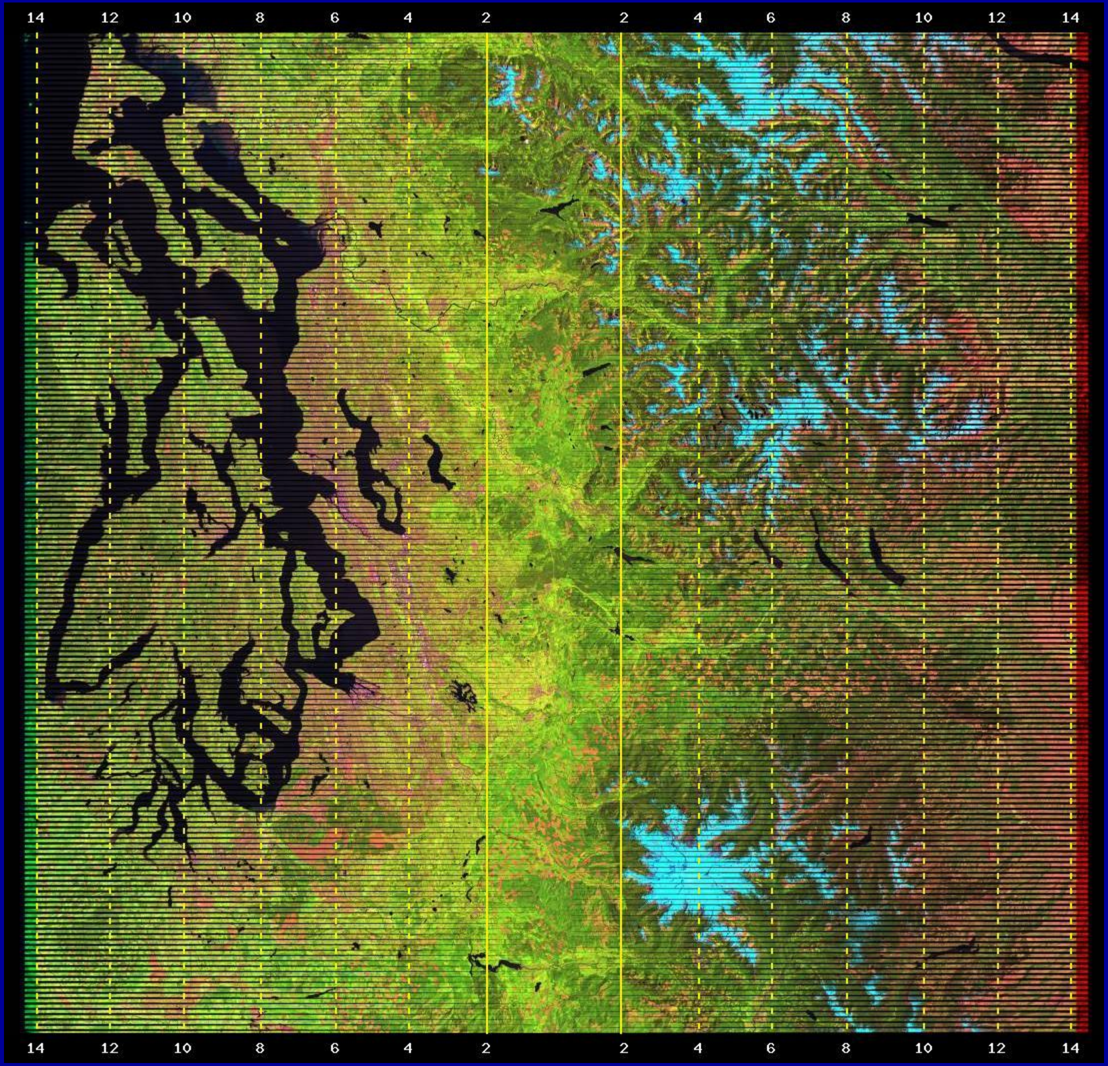
Gap Masks



#2 Scroll (0.02801)
#2 Scroll (0.02801)
#2 Band 1:L71071019_01920040802_B10.TIF
#2 Band 1:L71071019_01920040802_B10.TIF
ile Overlay Enhance Tools Window

Position of NCCN parks

MORA



Position of NCCN parks

NOCA